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THOMAS J. PIAZZA

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Thomas J. Piazza

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by

Thomas J. Piazza

Commander, Supply Corps, U. S. Navy

Submitted in partial fulfillment of
the requirements for the degree of

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OF NUMERICAL CONTROL

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ABSTRACT

Numerical control, a recent automation innovation, has been lauded for its advantages in reducing production costs. The application of numerical control to one facet of the Navy inventory management has been examined with a view to using numerical control programs in lieu of stock for certain items. The study concludes that the method proposed presents a practicable method of reducing total inventory management costs but not without the involvement of an element of risk and that numerical control standardization of machines and languages has not progressed to the degree that the method is practical now.

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CHAPTER I

Introduction.

An Industrial Revolution

Were a single characteristic to be attributed to the time in which we live it would most certainly be that of change. Everything around us has felt the dynamic tug of the time pulling toward more efficient utilization of the inputs to achieve a greater amount of output. The constant nagging by competition has wrought so many changes that the commonplace of today was undreamed of, except perhaps by Jules Verne, at the advent of this marvelous twentieth century.

Man's progress down through the ages has been governed by the sophistication of the tools he has developed. Progress was gradual over the centuries until the Industrial Revolution marked the awakening of technological progress. Subsequent progress developed at an accelerating rate as evidenced by the increasing mechanization of business and industrial production. The post-war years have introduced some remarkable changes in this long development continuum, not the least of which is automation.

We are in the midst of a second industrial revolution, the era of automation. Man's muscles are not being replaced or extended as they were in the first industrial revolution but this time it is man's brains that are being replaced. The functions once accomplished exclusively by poeple are more and more being performed by machines. These machines use synthetic intelligence to replace the brains of man in a wide variety of pursuits. "Machines do not in any way transcend man's intelligence, they very well may, and often do, transcent man in the performance of tasks."[1] Foremost among these machines is the computer.

The computer has grown from an electronic curiosity to a near-necessity in everyday business and industry operations. Less than two decades ago the computer was a much-speculated marvel, the attraction center of trade shows and scientific literature. Within this same twenty year period the rapid development of theory and data processing has vastly extended the former capacity for data handling so that new families of devices had to be created. Multiplying from the most austere beginnings these computerized families have invaded nearly every facet of commerce. The stream of technological improvements, characteristic of the computer industry from the start, is continuing at a steady pace and application concepts are becoming more sophisticated, pointing out more effective ways to tap the unused potential of machines.

The concept of automatization is not new for its roots reach back more than a century. Evidence of an automatic sawmill appears in the writing of da Vinci (circa 1496); an American, Oliver Evans, built an automatic grist mill in Redclay, Pennsylvania (1784) using elevators and conveyors; Charles Babbage's difference engine in England in 1822 was the forefather of today's computer; Blanchard's contour tracing gunstock lathe (1822) enabled automatic duplication of military gunstocks; C. X. Thomas built a desk calculator in 1833, and there were many other attempts to automatize the production process of various segments of business and industry.[2] These notable experiments in automation failed because of the lack of technical competance and the limiting methods of their times.[3] The twentieth century that followed, however, brought advances in technology so that automation became a scheme not just a dream of production methodology.

The computer, which has contributed much to the rapid growth of automation,

is a direct result of wartime demands for weapon positioning equipment. To meet the challenge of faster aircraft, research was conducted into better methods of tracking with antiaircraft weapons. The result of the investigations was a servomechanism utilizing closed loop circuitry.[4] From this body of knowledge was born the first military computer and from it the impetus of post-war automation.[5]

Inventory Management

Not all changes have been so spectacular as the development of automated assembly lines. One such example is inventory management. Inventory management has felt the influence of the changing times but has evolved at a slower pace from the era of intuitive to scientific management. At one time the assessment of success was in the reckoning of stores of goods - the inventories. But industrialization brought about a shift in emphasis from goods to liquid assets. Consequently, the philosophy of inventory management changed from the amassment of goods to money. With business and industry increasing in size the competition became keener and more precise methods of determining stock investment levels were sought. Intuitive stock determinations can result in surpluses which spell disaster and large inventories came to be viewed with alarm. The sophistication of advanced mathematical techniques offered a methodology of forecasting stock requirements which, at best, are an evaluation of the future based upon incomplete evidence. But until the genesis of the computer, sophisticated mathematics could be applied only to a limited range of items for obvious economic reasons. The computer encouraged the transition, then, from intuitive to scientific inventory management.

Intuitive and scientific management have in common the need to forecast sales for any item and the holding of stock against the expected sale. The

manner in which the forecasts are made and the amount of stock held differ greatly. The intuitive manager based his requirement prediction upon a "feel" for the market and the scientific manager uses probabilistic reasoning. Either way, Magee observed, "...one point is fundamental: a forecast will be in error to some extent no matter how sophisticated the techniques of forecasting are. The forecast error may be reduced somewhat but it still remains,"[6] scientific management aims to reduce this error to a minimum. It logically follows that the more accurate the forecast the more accurate will be the amount of stocks held for future sales. Through minimization of the forecast error the amount of stock held can be brought into closer balance with demand for the item at a smaller investment level, and with a consequent greater return on investment.

Were it possible to synchronize perfectly the delivery of material from production and the demand from sales there would be no need for inventories. The reason for maintaining inventories can be explained using the Keynesian approach. There are three motives for holding stock; the transaction, precautionary, and speculative: "The transaction motive results from the fact that it is not generally possible even in the case of certainty to synchronize perfectly the inflows and outflows of the commodity in question. Inventories are therefore held in order to compensate for the lack of synchronization. The precautionary motive results from the usual inability to predict demand exactly--most inventory problems are under risk--and the consequent need to maintain some kind of safety allowance . . . . The speculative motive arises when prices are rising or when there are expected changes in costs."[7]

Scientific inventory management uses the sophistication of mathematical techniques with the data processing ability of the computer to reduce the

investment level in inventory; but what of the original question of whether to stock a particular item? Once the decision has been made to carry an item in inventory against expected future sales the scientific methods can predict what amounts should be procured. But what of the item where need or sale of the item is truly uncertain? As if the question were not difficult enough it is even more so with the military item. "The extreme uncertainty of the situations that may arise, with respect to time of origin, duration, and even the nature of events, is almost without parallel in other enterprises, institutions, and agencies. There are intricate interactions of the decisions made concerning strategy, technology, and military worth, and these intricacies will themselves vary greatly with assumptions made as to the nature and timing of future events."[8]

The purpose of this paper is to investigate a method of reducing the investment level of inventory in items for which future need is extremely questionable. The method would join the potential of a production machine control process with a reduction in range of items carried in inventory thereby reducing investment.

[1]Norbert Wiener, "Some Moral and Technical Consequences of Automation," Science, Vol. 131, No. 3410, May 6, 1960, p. 1355.

[2]Developed from the Encyclopedia Brittanica, Encyclopedia Brittanica, INC., Chicago, Ill., 1961, Vol. 2, p. 784; and John Diebold, Automation. (New York: D. Van Nostrand, 1952), pp. 14-21, and James R. Bright, Automation and Management, (Boston, University, 1958), pp. 13-20.

[3]Eugene Grabbe (ed.) Automation in Business and Industry, (New York: John Wiley & Sons, Inc., 1957), p. 216.

[4]David O. Woodbury, Let ERMA Do It, (New York: Harecourt, Brace, and Company, 1956), p. 41.

[5]John Diebold, Automation, (New York: D. Van Nostrand Co., 1952), p. 19.

[6]John F. Magee, Production Planning and Inventory Control, (New York: McGraw-Hill Book Company, Inc., 1958), p. 116.

[7]Martin K. Starr and David W. Miller, "inventory control: theory and practice," (Englewood-Cliffs, New Jersey: 1962), Prentice-Hall, Inc., p. 17.

[8]Thomson M. Whitin, The Theory of Inventory Management, (Princeton, N. J., Princeton University Press, 1957), P. 165.

CHAPTER II

Machine Control

Numerical Control Concept

Automated machine control did not originate with the second industrial revolution. Automatic machine control was evident at the turn of the nineteenth cnetury. In Paris in 1801, Joseph Jacquard devised a method of controlling the operation of a loom through the use of perforated cards.[1] His method of weaving figured fabrics was so successful that by 1912 over 11,000 such looms were in operation.[2] Unfortunately, interest in the perforated card technique to control machine operation languished until the U. S. Air Force, seeking a way to supply small lot orders of complex parts, contracted for such a study with the Servomechanisms Laboratory of the Massachusetts Institute of Technology, in 1950.[3] Their research succeeded in effectively combining Jacquard's machine control with computerized machine path determination and its success rekindled interest in the perforated card technique. The resulting combination of techniques was to become known as numerical control.

The concept of numerical control is to guide the tool over the workpiece without human intervention in response to a series of instructions previously encoded in numerical values. Numbers always have defined values to the human mind and a specific number provides an immediate picture of a standard condition to the mind. However, when the number must be interpreted by a machine and coordinated with a series of other values the operation becomes very complicated.[4] Thus, the use of a computer developed into a practical necessity.

The numerical control concept utilizes a binary numerical system to

control specific and individual functions of machines. The method is used to calculate programs which will permit a machine to produce repeatedly with a high degree of precision specific parts and components. These programs, recorded as perforations in cards or tape, can be stored for eventual future use. When needed the tape is fed into a "reader" which controls the operation of a machine in much the same manner as a player piano.[5] For the latter, holes punched in a roll of paper correspond to positions of keys to recreate musical notes. The pattern of holes is prepared by a skilled musician to serve as a program for the operation of the piano. In much the same way, the pattern of holes in the numerical control tape is prepared by a skilled machinist to correspond to incremental distances of movement of the positioning drives of a machine. With the piano the player roll need not be prepared by a skilled pianist and similarly the numerical control tape does not require the services of a specialist in a particular machine.[6] Once the program is stored in the roll it is available whenever needed and will reproduce the stored pattern with unerring accuracy in exactly the same way each time it is played back. An essential difference is that numerical control also adds a feedback feature which serves to ensure the machine has done what has been directed and to warn the operator when it has not. The feedback sends back a signal directly from each machine feed to the controller to compare command with result.[7]

Machine Tools

The machine control thus developed has been applied to machines known as machine tools. Broadly defined, machine tools are manufacturing machines which produce work by removing material as chips or scrap from a workpiece

through some form of relative movement between a cutting tool and the workpiece.[8] More precisely defined by the National Machine Tool Builders' Association:

> "A machine tool is a power driven machine not portable by hand, used to shape or form metal by cutting, impact, pressure, electrical techniques, or a combination of these processes."[9]

To fulfill such a comprehensive definition there are many different types of machine tools which perform a variety of tasks and appear in a wide range of shapes, sizes, and configurations. Basically these machines can be categorized according to their technique of metal cutting, drilling, turning, milling, planing, grinding, and shaping. Regardless of the simplicity or complexity of a machine tool it will perform one or more of these basic operations, limited only by the demands of the work and the ingenuity of its designer.

For the purpose of numerical control there are two basic types of machine tool: discrete positioning and continuous path. Discrete positioning is the least complex of the two. The object of this type is to move the cutting tool, such as a drill, to a specified location and perform the desired operation. Other than the time required to reach successive points the path is immaterial. The principal consideration is to describe the location of the point with accuracy. Usually this point is the center of a hole which is clearly defined on blueprints. Whereas with the continuous path type of machine control it is essential to describe the geometry of the curve to the machining tolerances permitted by the specific machine. The cutting tool, therefore, must be continuously guided throughout its entire path. Describing the continuous path of a curve in space can involve a great deal of mathematics. By employing a general-purpose computer it is possible to reduce this task to a simplified, yet economical, operation.[10]

A Marriage

Employment of the numerical control concept to continuous path machines made the marriage of the machine tool with the computer a practical necessity. A machine tool must follow straight lines in the relative positioning of the workpiece and the cutting tool. Any curved surface on the finished workpiece is comprised of many thousands of straight line increments which aggregate to a curve. Assume a machine with two degrees of movement of a cutting tool which will be brought against a rotating workpiece. Then, in order to produce a curved surface on the workpiece, the cutting tool must be moved in successive horizontal and vertical increments to trace such a curved path. As can be readily visualized, the determination of the correct combinations of incremental movements increases in complexity with the irregularity of the surface curvature. Any additional dimensions of curvature or degrees of movement of the cutting tool will increase the scope of the problem. Manual determination of these increments is possible but not truly practicable, whereas the computer can perform the necessary calculation for the continuous tool path with comparative ease. The computer, therefore, is the heart of numerical control.

The computer simplifies preparation of the tool path on the perforated numerical control tape but actual programming remains manual. To prepare a numerical control tape, a part programmer must take a part or drawing and locate the path of the tool center for each cut. Especially important is the location of corners and where the tool changes direction. Starting with the tool located over a reference point, the part programmer describes the path of the cutting tool, and therefore the motions of the machine, from where the tool enters the workpiece to its exit at the end of the cut. Programming the

motion the cutter must make to produce the final shape of the workpiece requires that the programmer know the hardness of the material, the cutters available, the tolerances of part being machined, and the general characteristics of the machine, such as the power systems and limitations of the controls. Given the type of machine and the material to be machined, the part programmer works out the optimum cutting speed, decides the tool to be used, computes the distances, and calculates the total time for the cut. The distance the table must travel, the motion of the slide, and the movements of the head are converted to binary form by the computer.

An error that the part programmer must particularly guard against is the possibility of cutting tool-workpiece collision. The collision can occur when the cutter is being moved from one point on the workpiece to another. This move may be made as fast as 200 inches per minute in a discrete positioning operation. If the part programmer has failed to guide the tool around a protrusion of the workpiece above the plane in which he is operating, a collision can occur. Thousands of dollars worth of damage to the machine tool in the loss of productive capacity can result as well as the requirement for complete recreation of the tape.[11]

Computer-Oriented Language

To aid in the transition between the numerical description of the machine operations and the actual operations of the machine tool, computer-oriented languages were developed. The part programmer is able to describe an operation in everyday language and the computer performs the many calculations to translate these instructions into the sequence of statements of error-free instructions meaningful to the machine tool-controller combination. The

languages, then, were developed to enable the part programmer to describe machine tool operations in English-like statements. Acronyms like WALDO, APT, AUTOMAP, AUTOPOSIT, COMPAC, AUTOPROMPT, SPLIT, NUCOMP, SYMPAC, and others describe some of the languages developed.[12] Standardization efforts are currently underway[13] and a recent report suggests that APT will be the standard language.[14]

The objective of a numerical control system is to translate the instructions embodied in an engineering drawing into the orders for physical action of a manufacturing process. This can be accomplished in a number of ways and variations. The first step undertaken is for the part programmer to write the source program. Using one of the available languages, the programmer describes the geometry of the part. The source program, thus described, is fed into a computer which

(1) converts the source program into binary coded instructions,

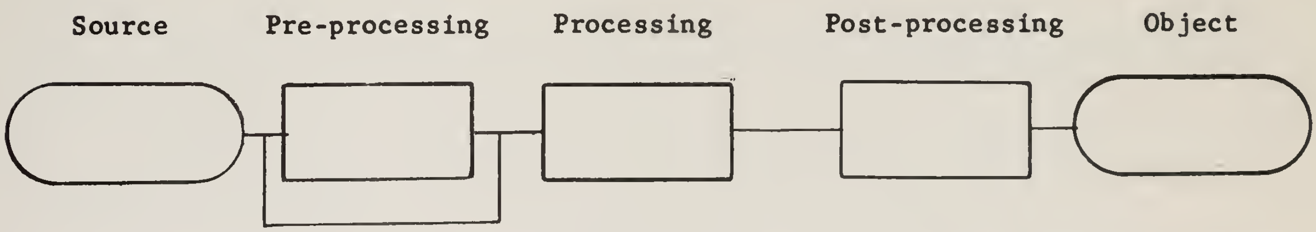
(2) translates language statements into specific mechanical routines,

(3) checks the source program instructions for error and reads out identification of errors located.

Still within the computer the source program is merged with information peculiar or characteristic of a certain machine tool. Since each manufacturer uses different components in the construction of a machine tool, these characteristics are especially important to preparation of the control tape. The operating characteristics of the machine tool selected to produce the part are as essential as the source program and must be an input to the computer to achieve the desired output. The output from the computer is a taped set of instructions for a particular machine tool to perform a sequence of physical

actions at the proper feed rate, the object program.

The preparation of the numerical control tape described can be identified as comprised of four functions: the source programming, pre-processing, processing, and post-processing.[15] The source program provides the input data required by the computer system written in a common language and also provides a plan for sequencing machine operations as well as part and tool definitions. Pre-processing is the function that provides for any computer programs that may be required to compute part dimensions not easily defined (and may be omitted). Processing is the translation of the source program language into the machining language and post-processing translates this generalized data into the format required by an individual machine tool-control system. Most systems encountered incorporate processing and post-processing in one operation of the computer to achieve maximum economy through minimized operating time. In this way the two operations can be accomplished with one computer run. It is also evident from the above description that pre-processing is not mandatory so that only two operations are externally apparent: source programming by the part programmer and object programming by the computer.[16]



A complete post-processor is made of two informational packages. First is the computer language description of the control and all of its operational features. Second is a computer language description of the machine tool. (Sometimes referred to as a geometry package.)

The description of the machine tool includes:

1. The limits of travel of each axis of the machine.
2. Maximum speed of each axis, the dynamics of acceleration, and other limitations on movements.
3. Particular auxiliary functions associated with the machine tool such as tool changes, spindle speed tables, and other special functions.
4. Any special motions such as twisting motions or dual heads.[17]

The numerical control system described illustrates a sophisticated application of computer techniques to machine tool control. Through the use of this concept of automation, parts are produced on one machine with unfailing repetition and quality at a rate greater than man could ever dream of emulating manually. Man's brains, in machine tool operations, were previously used to decipher and caliper instruction from blueprints, drawings, and job orders, and to translate the instructions into movements of the cutting tool and the workpiece. These actions have been replaced by the synthetic intelligence of the source program and the object program in this, the second industrial revolution.

[1]James R. Bright, *Automation and Management*, (New York: D. Van Nostrand, 1952), p. 13.

[2]John Diebold, *Automation*, (New York: D. Van Nostrand Co., 1957), pp. 19, 33.

[3]"Numerical Control of Machine Tools," *Business Management*, October, 1964, p. 79.

[4]"Automatic Control Slashes Forging Cost," *American Machinist*, October 25, 1954, p. 141.

[5]"Numerical Control," *American Machinist*, July 22, 1963, p. 76.

[6]James J. Childs, "Numerical Control and Personnel Requirements," *A Primer on Numerical Control*, pp. 123-4.

[7]"Automatic Control Slashes Forging Cost," *American Machinist*, October 25, 1954, p. 142.

[8]Charles R. Hine, *Machine Tools for Engineers*, (New York: McGraw-Hill Book Company, Inc., 1950), pp. 1-8.

[9]"Machine Tools . . . Today," Publication of National Machine Tool Builders' Association, Sixth Edition, Washington, D. C., September, 1964, p. 9.

[10]James J. Childs, "Numerical Control for the Machine Shop," *A Primer on Numerical Control*, May 1961, p. 93.

[11]*Introduction to Automatic Data Processing for Numerical Control of Machine Tools for the Federal Government*," IBM Manual E50-0022-1, 1964, p. 15.

[12]Robert Heslen, "Choosing An Automatic Program for Numerical Control," *Control Engineering*, April, 1962, Vol. 9, No. 4, p. 109.

[13]Frantz L. Alt, "The Standardization of Programming Languages," *Computers and Automation*, November, 1964, Vol. XIII, No. 11, pp. 32-36.

[14]Wallace E. Carroll, "Man and the Computer," *Sperryscope*, Fourth Quarter, 1963, p. 10.

[15]"The Users Course in Numerical Control . . . Applied to Machine Tools," Publication of National Machine Tool Builders' Association, Washington, D. C., December, 1963, p. 27.

[16]"Source Programming Manual for Numerical Control Contouring with the Auto-Prompt Processor," IBM Manual M & A 12, New York, May, 1961, p. 4.

[17]"The TWR APT Post Processor," Bunker Ramo Technical Bulletin, Publication No. 4014, Cleveland, Ohio, September, 1964, p. 1.

CHAPTER III

Technical Item Introduction.

Application of automation concepts have invaded inventory management as well as the manufacturing segment of industry. Utilizing the sophisticated techniques made possible through the use of computers, an inventory manager can effectively manage literally thousands of items with few employees, but management begins only after the item has been introduced into the inventory, i.e., after provisioning has occurred. Inception of the technical item is still largely a manual process aided by computerized pre-screening and pre-selection processes offered by data retrieval and identification systems.[1] There is no substitute for man in the provisioning process at this time.

A technical item is introduced into the military supply system through the provisioning process.

> "The provisioning process establishes the range and depth of items required in support of an end item for that period of time that extends from placing of the end item in operation until full support responsibility can be assumed by the supply system through routine replenishment."[2]

> "Considerations upon which the overall range and depth of supporting items will be based include, but are not limited to the following:
>
> (1) Expected replacement rate of the end item and its overhaul cycle.
> (2) Probability of failure of supporting item.
> (3) The degree of recoverability and repair turnaround cycle of repairable supporting items.
> (4) Relative cost of procurement concurrently with production equipment as compared with subsequent parts procurement.
> (5) Possible inability to obtain items by subsequent production without excessive costs or adverse effect on production schedules of other equipment.
> (6) Costs of storage and handling of items.
> (7) Prospective rates of use and obsolescence.[3]

Provisioning, therefore, resulted in many of the 414,000 items added to the military supply system in 1962 and of the 282,000 added in 1963.[4]

Many items are provisioned because of an inability to forecast with precision the failure of the item in-service. The net result of this inability is that the supply system carried a large number of items for which there are no sales and an investment loss when the items are eventually disposed of as surplus. These items are known as insurance items and like insurance were bought because of the uncertainty of the need for them. Insurance items are defined as: "Items for which there may be occassional intermittent demands not sufficient to warrant classification as regular stock items; but for which prudence requires that a nominal quantity be stocked for the reason that the essentiality of the items and the lead time required to obtain such items by purchase would create an unacceptable situation if no stock were carried."[5] At the time of provisioning the decision was made that the item might be required at some future date and that purchase would be more economical from an overall point of view than waiting to procure the item should a failure occur. In view of all the considerations, the decision can be supported with rational judgement, although, hindsight would challenge the wisdom of many of the decisions made.

The following table[6] shows the relative proportion of insurance items in the peacetime operating stock as of 1 July, 1964. It will be observed that 28% of the items are identified as insurance and 20% as provisioning. The significant difference is that the "provisioning" items are new and have not had an opportunity to experience a reasonable period for generation of demand.

ITEM COUNT

Material code	Non-repairable	Repairable	Insurance	Provisioning
1A	10,934			3,817
1E	681	8	765	1,536
1H	74,296	45	23,776	18,449
1N	40,824		15,826	58,098
2A	2,319	1,813	73,352	8,584
6A	2,229	807	6,602	13,915
8A	211			4,825
2N	1,282	5	27,601	753
4N	1,320	10	4,063	1,092
6N	290	3	160	381
8N	396		3,805	2,733
2R	126,913	27,833	4,887	
Total	261,295	30,524	160,837	114,183
	(46%)	(6%)	(28%)	(20%)

Procurement of insurance items for which anticipated sales never materialize is not an inexpensive proposition. The investment cost of the item is just one of the many expenses involved with the holding in inventory against possible future need. The cost to procure the item, the administrative costs to catalog and identify the item, the annual costs to manage it, the cost of disposal when replaced as a result of an engineering change to or retirement of the end item equipment, and the cost to withdraw the stock number from active files should all be considered. The magnitude of these costs is not readily available for many reasons but the importance is best illustrated by the annual cost to manage an item of supply. This cost has been variously estimated at over $114.[7] Added together, these costs make an expensive insurance premium which are spent to avoid the cost of down-time of an equipment. The cost is unimportant, however, if important items of equipment are not available when needed in fact, the fate of the nation may be at stake.

[1] *Inventory of DoD Technical Logistics Data Actions and Related Efforts*, January, 1964.

[2] "Navy Policy for Standards for Inventory Management," Department of the Navy Report NAVEXOS P-1500, p. 6-1.

[3] *Ibid*.

[4] "Item Entry Control Program," A progress report, Defense Supply Agency, March 1964, p. 18.

[5] "Navy Policy for Standards for Inventory Management," Department of the Navy Report NAVEXOS P-1500, p. A-1.

[6] Table developed from figures acquired by the Stock Finance Division, Bureau of Supplies and Accounts, Navy Department, in response to the stratification of inventory.

[7] "Item Entry Control Program," A progress report, Defense Supply Agency, March, 1964, p. 24.

CHAPTER IV

The Proposed Method

Source Program

The recent austere years have brought an increasing awareness of the need for precision in the field of inventory control. Limited budgets in a time of military technological expansion have increased the complexity of the inventory control problem. Some relief has been afforded by computer applications that permit management by exception and advances in scientific management provide methods of reducing investment level through such techniques as economic order quantities and variable safety level. The problem condenses to one of an input-output analysis of where best to spend limited funds to provide the greatest amount of protection against shortages of material in a supply system that experiences volatile demand.

The investment of funds in inventory in anticipation of demands for the material is a sunk cost of doing business of the military organization. The ability of a military unit to respond at instant notice can not be sacrificed through the saving the cost of a repair part. The pyramiding effect from the lack of a horseshoe nail is not complete fiction when viewed with our jet age vision, and downtime of individual equipments awaiting parts can be extremely costly to the nation if the military unit is incapacitated to retaliate. Employment of the numerical control technique to the inventory management problem may offer a partial solution to this funding aspect of the problem, however.

One possible approach to reducing investment of limited funds would be to stock a numerical control source program in lieu of the related insurance

repair part. During the normal provisioning cycle a true insurance item would be procured because of the precautionary motive, thus representing a guard against the uncertainty of the future. Since the source program identifies in English-like statements every operation of a machine tool to produce the finished part, it is, therefore, an engineering translation of the operations to produce the part. It represents one production step beyond the engineering drawing closer to the finished part. The price of the individual source program will be dependent upon the production complexity of the part but, with the exercise of selectivity, will constitute a smaller investment than for the related repair item. The cost of the source program is actually payment for the first phase of the manufacturer's production process.

The source program should be procured and stored without further processing to convert it to the object program. Two computer functions, processing and post-processing, necessary to produce an object program from the source program, should not be performed prior to the storage of the tape since performance of these functions individualizes the program to a particular machine tool-controller combination. At present there is not a high degree of interchangeability between the machine tools and the controllers made by the many manufacturers. The possible combinations are rife. Should the parts ever be ordered, the designated producer could perform these two functions on the source program to acquire an object program tailored to his exact machine requirements. Computer time for conversion of source to object program is minimal.

Storage of the source programs poses little or no problem. A convenient location could be at the program support Inventory Control Point,[1] within easy access of the Technical Department. In view of the technical nature of

the stored information the manuscript would be properly located there as are microfilm aperture cards and drawings of repair parts. The source program, as stated earlier, is a technical extension of the drawing oriented to the production process. Storage identification would be assigned within the provisioning cycle.

Storage space poses no real problem since one manufacturer reports stowage of 2000 tapes, averaging one hour in length, in two steel letter size cabinets. Tapes and program sheets are kept in envelopes.[2] Duplicating the master tape of a source program is easy, inexpensive, and quick, taking only a few minutes of time on a Flexowriter.

Supplying the Item

As a normal supply procedure, requisitions for items not available locally are referred to successively higher supply echelons until filled from stocks or procured by the program support ICP. This fact influenced the choice of the ICP for storage of the source programs which will be used in procurement of the needed repair part. Included in the procurement package with the procurement description or specification, reproduced copies of the source program could be furnished to prospective contractors. The manuscript and tape of the source program are general enough to permit a manufacturer with one of many machine tool-controller combinations to produce the part, yet, general enough, too, not to give one segment of industry procurement advantage. Bidders lists annotated to indicate manufacturers equipped with numerically controlled machine tools could be retained at the ICP to facilitate procurement solicitation.

Insurance items can justify the inventory investment as protection against extended downtime of the parent equipment awaiting parts while the

ICP attempts to procure them from industry. To a lesser degree this same protection is afforded by custody of the source program. Lacking only computer operation to produce the desired object program which will control the item manufacture, the investment in part programming well in advance of the requirement saves time in the manufacturing process. And production time savings with numerical control is one of the principal reasons for its gaining popularity with industry. Some typical reports of the savings are:

1. turbine bars are machined in forty five minutes that conventionally takes sixteen hours;[3]

2. drilling time for sixty five holes of five diameters in an aluminum mounting plate was reduced from sixty to sixteen minutes with a corresponding reduction of setup time from five to three hours;

3. and for machining a gear housing the time was sliced from sixty five to twenty one minutes.[4]

Another manufacturer reports; "When production . . . was shifted from up-to-date well-tooled conventional machines to numerically controlled machines, time savings were substantial:

> the rear carriage is now machined in 8.8 instead of 18.2 hours; the tailstock now takes only 8.3 instead of 15.5 hours; and the front carriage is machined in 4.8 instead of 8.9 hours."[5]

Savings in production time like these reported are common, and incidentally, should pass on to the purchaser in the form of reduced prices.

On the deficit side, however, is the element of risk involved in stocking only a source program rather than the item. An emergency requirement with a short deadline delivery date could result in unacceptable downtime of vital equipment. Compared with the downtime for the item had it not been procured at provisioning, stocking the source program represents an improvement of the situation. Item selection, without question, is the foundation of effective equipment support. Military essentiality codes[6]

(MEC) offer a basis for selection of items with relatively low risk to utilize the numerical control program technique. Items selected could be identified with an appropriate source, maintenance, and recoverability code.[7] To provide for the possible later occurrence of a requirement, an open contract with a machine shop or Navy industrial activity would be a ready facility to produce a part, in a matter of hours, to meet the bona fide emergency. Another possible source of manufacturing capability would be a contract with the prime contractor, or his vendor who made the parts for the equipment production contract, to store the object program with related jigs and fixtures, pending such an emergency requirement. However, an investigation of this method may reveal that it is more expensive than stocking the item. Transmission of a source program anywhere in the world is simplified by the many systems of communications which will accept binary coded information. Availability of these communication systems diminish the risk involved with the proposed technique.

Previous discussion has been simplified for clarity of exposition and it would appear that stocking the source program is all that is required to represent the production process for an insurance item. In truth this is the major portion, but the dimensions and configuration of the machinable billet, the related jigs and fixtures along with a set of operator's instructions, are necessary to complete the description of the repair part. (It is conveniently possible to store this information in the source program as plain language text.) Although it is recognized that the use of numerical control utilizes fewer jigs and fixtures than conventional means,[8] those required in numerical controlled machining must be identified as commerically available vendor items[9] or their design illustrated. In addition, the operator must be

given instructions for set-up of the part in fixtures and/or jigs and reference point location for starting the numerical controlled operation. Together these comprise a complete package for production purposes.

Hindsight is generally better than foresight and we question the judgement of the provisioner each time an item is disposed from inventory without ever experiencing a single issue. Reports such as the test conducted on twelve submarines over a four year period showed that 75% of the technical items experienced no demand and of those that had demand, 70% were for one unit.[10] Obviously, procurement of a source program for the item which will experience no demand system-wide would net a savings to the government. But no one has such remarkable foresight as to be able to forecast items in this category so the provisioner buys insurance items. However, deferment of procurement until the first recorded demand for questionable items certainly could save the government the warehousing and stocking cost for the deferment time period. Holding costs alone are estimated at one percent of inventory. Another advantage to utilization of deferred procurement is that the decision is delayed on the quantity to stock until after the end item equipment has been installed and operating, so that more is known about the external environmental factors, e.g., the nature and kinds of failures common.

The proposed technique of using a numerical control source program does not attempt to solve the real problem of stretching a small amount of funds to cover a large number of item requirements. It does offer a method of investing less money on the stockage of insurance items with somewhat less protection, much like a reduced insurance policy coverage requires smaller premiums. From an input-output analysis it would appear that a smaller immediate investment would afford the same range of items but with less stock depth. For items where the risk of a stockout is intolerable there is an

[illegible]

[illegible]

[illegible]

option plan available. The option is to buy a drastic reduction in the normally provisioned quantity and a source program in lieu of the balance. Should reprocurement ever be necessary, the availability of a source program would provide deferred procurement advantages with a savings in production set-up costs.

[1]"Policy and Principles Governing Provisioning of End Items of Material," SECNAV INST. 4423.2A, 7 April 1958, pp. 2-3.

[2]"Over 2000 Parts Programmed for N/C," Automation, November, 1962, p. 8.

[3]H. Solow, "How to Talk To Machine Tools," Fortune, March, 1962, p. 184.

[4]"N/C Gives Marketing Edge to Job Shop," Steel, May 4, 1964, p. 102.

[5]Leo Aramovich and Clifford Breyley, "Making an N/C Department Pay," American Machinist, December 10, 1962, p. 116.

[6]"Fleet Military Essentiality Coding (MEC) Program," OPNAV Instruction 4423.1A, 23 November 1962, pp. 1-5.

[7]"Policy and Principles Governing Provisioning End Items of Material," DoD Directive 3232.4, 2 April 1956, p. 2.

[8]Carl W. Spoerer, "Effective Utilization of the Milwaukee-matic and Avey Turret Drill," ASTME Technical Paper SP 62-51; Detroit, Michigan, 1962, p. 6; "Special Report: Numerical Control," Steel, Vol. 154, No. 18, 4 May, 1964, pp. 98-112, and others.

[9]Frank W. Wilson, ed., Handbook of Fixture Design, (New York: McGraw-Hill Book Company, Inc., 1962, Ch. 15.

[10]M. Denicoff, J. Fennell and H. Solomon; "Summary of a Method for Deriving the Military Worth of Spare Parts," Naval Research Logistics Quarterly, Vol. 7, No. 3, September 1960, p. 221.

CHAPTER V

Relevant Costs

Programming

In the consideration of any new proposal or innovation the wise manager investigates the costs attendant with the proposed versus the installed. There have been a number of studies which have analyzed the costs of conventional versus those of numerical control for the production of the same item. These studies are recent but not current in the respect that the past three years have introduced a programming language for three dimensional numerical control which would have simplified the studies had it been available earlier. Industry associations and the Armed Services saw numerical control as "the baby figure of the giant mass of things to come"[1] and have invested considerable effort in the development of numerical control languages and machinery.[2] Largely experimental in 1955,[3] the technique of numerical machine control has advanced a long way with a concommitant price lowering from the high experimental.

Many tests of feasiblity of numerical control have been conducted in an effort to appraise its practicability. Under Air Force sponsorship, the Aluminum Company of America evaluated the numerically controlled machining of forging dies and concluded (in 1960) that the cost of numerical controlled processing was not competitive. A brief resumé of their findings is tabulated below:[4]

Die No.		Conventional	Total	NC	Total
14206	1st set	$1463.		1521.50	
	2nd set	1463.	2926	528.	3049.50
14222	1st set	$ 721		1182.50	
	2nd set	721.	1442	432.	1614.50

It is quickly apparent that the setup costs for a numerical control program were more expensive at the outset but once procured were not repetitive as were conventional setup costs. For the dies tested, a production quantity of three or more of each type would have been less expensive using N/C methods.

A companion evaluation of forging dies under numerically controlled methods was conducted with the following results, tabulated below:[5]

Die Block	Conventional	NC
W.G. 20221	640 hrs.	675 hrs.
W.G. 35007	115 est.	179.6
80479 1st set	127	
2nd set	93	48.9 hrs

As with the ALCOA evaluation test, the results are far from conclusive to prove either method is superior in any respect.

In 1957, the Navy Bureau of Weapons contracted with the Stanford Research Institute (SRI) to evaluate the retroactive fitting of numerical control to conventional production machines. Four different airframe manufacturers, each using a different machine tool, were employed to manufacture standard test parts. The results of conventional machining time and cost per unit was compared with that of the retrofit numerical control machining for the individual item as well as batches of fifteen (produced in two lots of forty five). It is significant to note that the overall time per unit produced in batches was greater for conventional machining but the price of each unit produced under numerically controlled methods was greater for single unit production. The SRI findings support the advantages generally attributed to numerical control of shortened manufacturing cycle time, reduced special tooling, and lower overall manufacturing time. It is reasonable that single units of numerical control production should be relatively expensive due to

the investment in part programming and computer processing.[6] Table I provides a summary comparison of the conventional machining with the numerical control retrofit in the SRI project.

Still another research contract, under Air Force auspices, investigated the numerical controlled milling and profiling of dies, templates, forgings, and electrodes of aircraft quality. During the evaluation program it was found that when more than one die of the same configuration was required, the economics were definitely in favor of the numerical control method. The researchers learned, too, that the programming and tape preparation time for a single die was approximately twice that of the machining time. The results of their studies are summarized in Table II, Comparison of Numerical Control to Conventional Machining Time. Even a cursory scrutiny of the table reveals that for a single unit production neither conventional nor numerical control method is universally superior.[7] Based upon the evidence of this and other studies, it would appear that numerical control does not compare unfavorably with conventional machining of dies for single unit production.

A trade magazine article, appearing in late 1959, compared the preparation and machining times for various parts produced on a numerical control versus a conventional profile milling machine.[8]

Vent splice fitting	N/C	Conventional
Tool design	200 man hours	300 man hours
Tool fabrication	1500 " "	2100 " "
Production planning	300 " "	80 " "
Data Processing	10 " "	
Machine set up	10 " "	18 " "
Total preparation	2020 man hours	2498 man hours
Machine time	8 hours	10 hours

	N/C	Conventional
Fitting		
Tool design	279 man hours	390 man hours
Tool fabrication	2166 " "	3083 " "
Production planning	35 " "	16 " "
Data Processing	8 " "	6 " "
Total preparation	2491 man hours	3495 man hours
Machine time	7 hours	11 hours

More current is another article from a trade journal that provides a comparison of costs between a numerical controlled and a conventional machining center. Pertinent figures have been summarized in the table below to illustrate some of the costs preparatory to actual production:[9]

Antenna mount	N/C		Conventional	
Planning	6 hr at $10.	$ 60.	96 at 8.50	815.
Programming	66 hr at $10.	660.		
Tape preparation	4 hr at $5.50	22.		
Tool design	56 hr at $7.50	420.	218 at 7.50	1635.
Tool fabrication	17 hr at $6.50	1100.	672 at 6.50	4370.
		$2262		$6820.

Housing	N/C			
Planning	2 at $10	20.00	16 at 8.50	136.
Programming	22 at $10	220.00		
Tape Preparation	.4 at $5.50	2.20		
Tool design	10 at $7.50	75.00	90 at 7.50	675.
Tool fabrication	24 at $6.50	156.00	232 at 6.50	1510.
		473.20		$2321.

It is quite apparent from the two magazine articles that the preparatory costs for the items compared is markedly less for numerical control. In addition, tool design and fabrication constitutes the major expense for the conventional method, with fabrication amounting to about two thirds. Even with the exclusion of tool fabrication, the preparatory costs for numerical control are the lesser of the two.

As stated earlier, the computer time is a minimal part of the cost of numerical control. Since there has been no known study of using the source

program in lieu of stock for the item, the computer time for the source program part of the operation has not been set forth separately. More economic advantage is to be gained by using the computer to prepare the source and object programs in one continuous operation, and, secondly, manufacturers know the machine tool-controller equipment combination to be used in production so that there is no advantage to preparing a separate tape of the source program. An example of the total programming time compared with the computer time was published by the Aerojet-General Corporation for the contouring of a missile component with intricate grooves machined to extremely close tolerances. The assumption being made here is that the comparison is more representative than atypical for these parts in the total use of numerical control, since the stated purpose of the article was to illustrate that the "N/C missile lathe can do the job four times as fast as conventional equipment, to the most exacting specs."[10]

	Manuscript preparation Time in hours	Computer time in minutes	Computer cost per program
Operation No. 1	35	3.7	$33.00
Operation No. 2	30	2.52	22.00
Operation No. 3	45	1.78	16.00
Operation No. 3A	90	12.93	114.00
Tool Setting	4	2.18	19.00
Total	204	23.11	$204.00

Inventory Investment

Although the part programming expense represents a significant share of the production costs and a potential area of savings, there are other costs to consider. The use of N/C source programs, as stated earlier, will reduce the investment in inventory either totally or partially on a deferred

procurement-reduced depth basis. In addition, other costs of inventory management are worthy of consideration. Implicit in the cost of holding an inventory is the time-preference rate. This internal interest rate is normally defined as the return that might be reasonably expected if the money used to purchase inventories were invested in other ways. The time-preference rate is frequently estimated at 3-5%.[11] Using the source program proposal could result in the savings of this part of the holding costs.

No discussion of inventory costs would be complete without mention of the obsolesence and the storage costs. The first products of technological innovation are the technical repair parts and, accordingly, are the first victims of change. Since the source program represents the actual repair part, its obsolescence rate will be that of the associated part so there is really no appreciable change from the governmental point of view. However, it should be abundantly clear that when an item becomes obsolescent, or even obsolete, through modification of the parent equipment, all stocks must be disposed. Not so with the source program tape which can be altered to accommodate to the changes in the repair part.[12] The programming and computer costs to alter a program tape to provide the engineering change are markedly less than the costs to dispose of obsoleted stock and reintroduce a new item into the supply system inventory. Storage cost for an item is more elusive to estimate since much of the cost is fixed in real property investment and salaries. For this reason storage costs have been variously estimated, one per cent of the inventory value being currently in favor.

Summing the relevant costs presented, it appears that:

1. Part programming for production is generally more desirable for items which will be produced in quantities greater than single units,
2. Production time for numerically controlled machining is less than by conventional means,

3. Computer time to convert a source program to an object program is relatively small and inexpensive,

4. Tool design and fabrication involves less with numerical control than conventional methods,

5. Inventory investment expenses are directly related to changes in inventory, the time-preference rate, the storage and obsolescence rates, the total of which is less for a decreased inventory size.

[1]William Shakespeare, "Troilus and Cressida," The Complete Works, G. L. Kittredge, ed., Boston, 1963.

[2]John Diebold, "The Revolution That Fails To Take Place," Advance Thinking, Report of the Proceedings of the 61st NMTBA, May 1963, pp. 97-111.

[3]James R. Bright, Automation and Management, (Boston: Harvard University, 1958), p. 19.

[4]Callender, A. R., and Alkire, D. I., "Evaluation of Numerically Controlled Machining of Forging Dies," Aluminum Company of America Final Technical Engineering Report AMC Project 7-667b, April, 1961, pp. 48, 50, 96-100.

[5]Swift, A. H., Brunner, W. C., "Evaluation of Numerically Controlled Machining of Forging Dies," Wyman-Gordon Company Final Technical Engineering Report Project 7-667a, September, 1960, pp. 12, 24, 28.

[6]"Evaluation of Retrofit Applications of Numerical Controls," Stanford Research Institute, Final Report of Projects Nos. ISU-3217 and ISU-3746, September, 1962, Appendix D.

[7]"Evaluation of Numerically Controlled Machining of Forging Dies," Harvey Aluminum, Incorporated, Final Technical Engineering Report 60-7-667, December, 1960, pp. 1-37.

[8]"Tape Controlled Profiling," Automation, October, 1959, p. 83.

[9]"The Economics of a Machining Center," Steel, Vol. 154, No. 18, May 4, 1964, p. 107.

[10]"Tape Turning of Complex Grooves," American Machinist, November 25, 1963, p. 74.

[11]James W. Prichard and Robert H. Eagle, Modern Inventory Management, (New York: John Wiley and Sons, Inc., 1965), pp. 85-86.

[12]L. S. Linderoth, Jr., "Economic Justification for Numerical Control," Automation, November, 1962, p. 6.

CHAPTER VI

What the future holds.

American builders of machine tools have produced numerically controlled machinery for over a decade and the future has been augured as being very bright for rapid growth. The optimism harkens to the spectular rate of increase of numerical control applications but discounts the disappointing size of the equipment population. What the future holds in store is worthy of scrutiny.

After World War II, there was a great surplus of machine tools brought about by the rapid industrial expansion to meet the demands of wartime production. With the coming of peace, the postwar market for newly-built machines was decreased by the available machine tools released from war production. The result was a drop in sales of machine tools with a corresponding decrease in the capacity to produce them. The cycle repeated itself with the Korean conflict but wartime sales did not multiply so rapidly nor fall off so sharply with the resumption of peacetime production. Two other reasons contributed to the higher level of sales after the uneasy Korean peace; the increasing population demanded more consumable goods and the advances in production techniques lowered prices, thus increasing both, supply and demand for machine tools.[1]

Sales of numerical control machines in the early part of 1950 were confined to the government and the segment of industry that could afford to experiment. The first numerical control machines were very large and expensive, best suited to large volume production runs of relatively stable design products.[2] Through continued research, the average price was brought

down and the volume of sales up,[3] as shown by the following table:

Year	Quantity	Value(million)
1954-8	193	$31.2
1959	203	17.3
1960	402	34.7
1961	518	48.3
1962	504	27.7

The discrete positioning type, which sells for less than $125,000, represented 85% of the market and continuous path machines accounted for the balance.[4] To increase sales further, some discrete positioning models were recently re-engineered with a consequent unit price lowering from fifty to fifteen thousand dollars, placing it within the price range of the very small manufacturing enterprise. In addition, increased sales of the lowered price machines should make used equipment available, opening a second market for the numerical control machine tools.[5] By 1962 there were 1820 numerically controlled machine tools in use in industry and one year later showed an increase of more than a thousand.

Industry	1962[6]	1963[7]
Ordnance	108	60
Primary Metals	12	6
Fabricated Metals	135	99
Machinery (except elec.)	747	1356
Machinery, electrical	172	414
Transportation Equipment	494	815
Instruments, Related products	28	88
Others	124	
Total	1820	2838

The numerical control population in the succeeding year exceeded four thousand in the metal cutting industry,[8] but it does not compare with the potential market of over two million machine tools.[9]

Savings through the utilization of numerical control are the subject of

many articles offering inducement to the expansion of N/C. But the hoped-for population explosion has not occurred. The advocates of numerical control continually assure that time savings in production are not the only benefit, that scrap losses reduce through the repeatability[10] feature of tape control, saving time increases yield which reduces need for capital investment in machinery and plant space,[11] and computer and part programming services are available for hire.[12] A computer to translate instructions to machine tool language is unnecessary, a trained engineer can prepare a tape on a desk size machine similar to a flexowriter. For the manufacturer lacking the engineer to prepare the tape, there is a growing industry of part programmers who offer this service.[13] Availability of these two solutions to the expensive tape preparation problem extends to even the very small manufacturing business the use of numerical control. Yet, the growth of the N/C population has been disappointing.

The principal obstacles to the growth of the numerical control population have been largely overcome and sales should increase. Present designs defeat the high initial cost of conversion to N/C, permit use without the expense of computerizing, enable economical production runs of low volume, and increase flexibility of operation. Added to this, the fact that sixty four percent of machine tools in use are a decade old[14] gives reason to believe that more industries will convert to numerically controlled operations, although the optimism expressed by Paul V. Stanton of Pratt-Whitney for 70% conversion by 1970[15] does not appear realistic. Continued research will add to the growing list of N/C applications as evidenced by a recent experimental model that translates dimensions from a clay automobile model into digital data.[16] The principal obstacles hurdled, the future appears one of optimism for numerical control.

[1]National Industrial Conference Board, The Economic Almanac 1964, New York: National Industrial Conference Board, 1964.

[2]"Automation on the Assembly Line," Dun's Review, December, 1964, p. 37.

[3]"BDSA Survey Shows Who Buys Numerical Control," Steel, 153:43, November, 1963, p. 154.

[4]"Tape Can Run The Machine Better," Business Week, August 30, 1963, p. 101.

[5]"Another Coming of Age," Business Week, February 7, 1964, p. 116.

[6]"BDSA Survey Shows Who Buys Numerical Control," Steel, November, 1963, p. 154.

[7]"N/C machine selection is affected by product," American Machinist, July 22, 1963, p. 72.

[8]"Numerical Control of Machine Tools," Business Management, October, 1964, p. 79.

[9]Burnham Finney, "Inventory of Machine Tools in Place," Advance Thinking, Report of 61st meeting of NMTBA, May 2, 1963, pp. 25-32.

[10]John Rudolf, "Now--a Tape Controlled Machine in the Shop, "Practical Automation, New York: McGraw-Hill Book, Co., 1957, p. 185.

[11]"N/C Gets a New Chore," Business Week, August 3, 1963, p. 54.

[12]H. Solow, "How to Talk to Machine Tools," Fortune, March, 1962, p. 121.

[13]John A. Nylander, "N/C centers serve small shops," American Machinist, February 4, 1963, pp. 56-7.

[14]Burnham Finney, loc. cit.

[15]"N/C Tools Poised for Big Jump in Numbers," Iron Age, January 31, 1963, p. 25.

[16]"Breakthrough in Autodom," Steel, June 22, 1964, p. 27.

CHAPTER VII

Summing up.

Numerical control has changed the basic concept of manufacturing and could, conceivably change inventory management concepts. In this age of innovation, utilization of numerical control for inventory management could contribute to solution of the dilemma of providing the greatest range of stock protection with small investment. The tests of innovation for inventory management are: responsiveness, economy, and compatability.

Any inventory management system should be responsive to the demands of the market. In this respect the military market is little different from the commercial. One very essential difference is that the military supply system carries a preponderance of technical repair parts, which by their very nature are directly related to specific equipments, and generally are required on a sporadic and difficult to predict basis. Technical repair parts are added to inventory stock "to assure that items required to support and maintain end items and components being introduced into service will be available in the appropriate segments of the supply system, and at maintenance echelons, when needed ..."[1] This objective is most easily satisfied by an extensive range of stock to meet any and all demands of the consumer. Within this range of stock there will be a large proportion of items for which demands will be few and far between and some items for which demands will never occur.

To preclude or delay procurement of these random demand types of items, it has been proposed herein that a numerical control source program be procured in lieu of the item. Should a requirement be generated for the item, the source program would be utilized in its procurement and subsequent

production. Such a technique could be responsive (1) if the manufacturing contract were in effect and current, (2) if the source programs were transmitted to the manufacturer with celerity, and (3) if delivery of the newly-manufactured repair part were quick. Service contracts and military installations can provide for responsive manufacturing service and modern data transmissions sytems eliminate the question of delay in transmitting source programs. And lastly, delivery of the item, then as now, is unchanged no matter when or how the item is manufactured. Use of the source program technique could provide a responsive means of satisfying consumer demands for insurance items but not so responsive as the carrying of the item in inventory since the part must be manufactured after the source program is converted to an object program.

There is much to be said about the economy of the source program inventory method. First, it should be reiterated that adoption of any technique which decreases the range of inventory will involve a degree of risk. With the source program technique this risk can be decreased through skillful selection of items or limiting the selection to redundant equipment. Once the items are selected it is apparent that procurement of only the source program will be less expensive than the inventory investment and the associated costs to carry the stock in one or more locations. Regrettably, this is an assumption which has neither been proved nor disproved from available data. What has been demonstrated is that an item produced by N/C methods compares favorably in price with the same item from conventional machining methods. Whereas, within the military provisioning consideration, the true acquisition cost of the item is from the production run which is producing parts for integration in the equipment manufacture.

Source program inventory management offers several economic advantages which are worthy of mention. The source program constitutes an investment in the production setup which is a onetime cost no matter how often the part is produced. Many different manufacturers can produce the same item with the same degree of precision from one source program tape. The only cost additive to the source program tape is for conversion to the object program and is negligible. Another significant feature is the part programming investment is not lost if the repair part is modified somewhat through design change because the tape can be corrected easily. Part programming costs for similar items are not repetitive because, as in the case of right and left pieces, one program can be adjusted to meet both needs. These are advantages worth considering.

Is the source program technique compatible with present systems? The question should be answered in the context of the supply system and for industry. In the present Navy supply system there are two current software techniques that offer somewhat of a parallel to the source program method. Extant in the supply system are 'paper stock numbers' which are identifications of items but for which no stock has been procured. There are also component identification numbers assigned to other items but neither is there stock nor a proper stock number. When a requirement is generated for one of these two kinds of items a purchase action follows. The same procedure would apply to the source program item. For this reason it is believed that the source program technique is compatible with the present Navy supply system.

Compatibility of numerical control source programs in industry presents more of a problem. As stated earlier, there are a number of computer-oriented languages used in part programming. Of this variety of languages, there is

not a high degree of standardization among the four thousand users of numerically controlled equipment and certain languages are not acceptable by other computers. The problem is recognized by industry who has their associations working on the problem of standardization of languages.[2] Once industry has agreed to standardize the computer language for numerical control, the Navy can issue policy regarding the programming language requirement, as was done with computers for business applications.[3] Until such time as there is more standardization of computer-oriented language for numerical control application, use of the source program method for inventory control is limited to the manufacturers employing the language selected.

The source program method, proposed as an inventory management technique, has been appraised in the context of its responsiveness, economy, and compatibility. The method compares with favor on each point within the military organization but lacks compatibility within industry. Because the use of numerical control for production is still in comparative infancy, compatibility poses a real problem.

[1] "Military Services - Defense Supply Agency Provisioning Responsibilities." DSA Regulation 4140.35 of December 3, 1963, p. 1.

[2] Henry Tholstrup, "Punched Tape" Data Storage Handbook, Pittsburgh: University of Pittsburgh Press, n. d., p. 8.

[3] "Department of the Navy Atuomatic Data Processing Equipment (ADPE) Program" SecNAV Instruction PI0462.7A, February 26, 1964, p. V-4.

Conclusion and Recommendation.

The conclusion reached as a result of this investigation is that utilizing the numerical control source program in lieu of the stock for certain insurance items presents a practicable method of reducing total inventory management costs. The method offers distinct advantage to the supply system but not without the involvement of an element of risk, although the risk can be diminished through skillful item selection and the award of advance manufacturing service contracts for technical repair parts. There is advantage to be gained through use of the proposed technique but neither numerical control utilization nor computer language standardization would warrant further exploration of the technique at this time. It is therefore recommended that additional investigation of the proposed method be delayed until such time as a more representative segment of industry has adopted one language and has installed numerically controlled production equipment. During the interim, consideration should be given to the all-important consideration of item selection.

TABLE I

MACHINING TIME AND COST COMPARISON

Part	Conventional				Numerical Control			
	Time		Cost		Time		Cost	
Units	1	15	1	15	1	15	1	15
GAEC 021 Engine mount web	14	1.1	$ 186	$ 16	19	.7	$ 292	$ 18
GAEC 028 Attach fitting	70	2.6	777	45	53	1.2	717	36
CVA 060 Arresting gear arm	618	2.8	7002	183	272	1.0	3201	87
MAC 033 Closure beam fitting	118	2.8	1244	52	203	1.4	2597	80
MAC 543 Outerwing spar	254	5.4	3034	120	620	1.8	7130	187
MAC 880 Closure door frame	215	5.6	2216	104	400	1.5	5217	139
GAEC 009 Bracket	60	6.3	668	82	92	3.3	1275	81
MAC 379 Keel support Beam	330	15.8	3750	240	309	12.4	4760	308
MAC 537 Landing gear rib	846	15.5	9711	374	490	5.1	5765	210
NAAC 217 Fuselage frame	110	50	1261	566	454	17	6326	415
NAAC 350 Landing gear attach	728	241	8274	2755	1367	120	20,121	2431
NAAC 348	516	39	5862	549	892	21	11,661	608
Total	7389 hrs	388.6 hrs	$82,608	$5086	6849 hrs	186 hrs	$97,617	$4600

[illegible]

TABLE II
COMPARISON OF N/C TO COMVENTIONAL MACHINING
(in estimated hours)

Die No.	0966	0929	0931	0533	0966	1062	1090	0855	1165	0207	Total
Times					N/C						
Program	20	28	37.5	43	3	1.5	13	22	32	23	223.0
Tape Preparation	14	5	14.5	13	15	38	16.8	26.2	30.4		172.9
Setup	2	5	2	60	4	46	30		2		151
Machining	1	30	39	12	26	39	12	20	35	34	248
Bench Work		12	7		8			4	10	4	45
Total	37	80	100	128	56	124.5	71.8	72.2	109.4		839.9
Times					CONVENTIONAL						
Templates		2	14	24	6	3	13	5	5	12	84
Layout	8	3	8	8	9	2		4	8	6	56
Setup		10	5	92			48				155
Machine		10	95	50	47	60	20	26	68	38.5	464.5
Bench Work	10	20	8	6	15	4	6	4	20	4	97
Total	18	95	130	180	77	69	87	39	101	60.5	856.5

[illegible]

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